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Water Quality Assessment of Surface Water at the Urban Area of An Giang Province, Vietnam

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ABSTRACT

The development of residential areas in the trend of urbanization and the development of industrial parks and clusters have caused risks to reduce the surface water quality of the Mekong River in An Giang province. This study was conducted by sampling surface water affected by urban areas and affected by industrial parks/clusters (seven sampling points) in June 2021 and analyzing the parameters of temperature, pH, DO, TSS, COD, BOD_5, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, Coliform, As, Pb, Hg, Benzene hexachloride, Dieldrin. The analytical results of water samples were compared with the National Technical Regulation of Vietnam. The water quality index was calculated according to the technical guidelines of the Vietnam Environment Administration (VN_WQI). The results show that domestic and industrial wastewater has polluted the surface water of the Tien River and the Hau River, two important rivers of the downstream Mekong River, flowing through An Giang province. The pollution shows in parameters of TSS, DO, BOD_5, COD, $N\text{-}NH_4^+$, and Coliform that exceeds allowable limits. However, other parameters such as temperature, pH, $N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$ are mostly at the acceptable range and within allowable limits. Based on the WQI, most of the water quality at the sampling points is poor. Therefore, it is recommended that people not directly use the Tien River and Hau River water in

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An Giang for drinking and domestic purposes. It is necessary to apply appropriate water treatment measures. In the coming time, authorities need to monitor and take appropriate measures to treat and manage wastewater from urban areas and industrial parks/clusters.

Keywords: Domestic wastewater, industrial wastewater, Mekong surface water, water quality

INTRODUCTION

An Giang is a province in southwest Vietnam located downstream of the Mekong River. The province is the first land area receiving water from the Mekong River at the northwest border, with Cambodia divided into two main courses (known as the Tien and Hau Rivers). An Giang occupies an important position in the Mekong Delta, with the terrain of hills and plains lying along the Hau River and the Tien River, branches of the Mekong River. An Giang has the potential to develop agriculture, commerce, services, and tourism. In the context of international integration and economic development, the environment of An Giang province is under increasing pressure, especially water pollution, which has affected the supply of freshwater for agricultural irrigation, domestic use, and industry (Shipin et al., 2005; Khanh et al., 2013; Khanh et al., 2015; An Giang Center for Environmental Monitoring and Techniques, Resources, 2019; Van et al., 2020). The development of residential areas in the trend of urbanization and the development of industrial parks and clusters have caused risks to reduce the surface water quality of the Mekong River in An Giang province. Therefore, it is necessary to assess the effects of domestic and industrial wastewater on the surface water quality of the Mekong River in An Giang province.

Water quality monitoring is critical to identifying problems and tackling pollution. The Mekong River is one of the world's largest rivers. The water quality of the Mekong River is the great interest to many researchers in the world (Wilbers et al., 2014; Chea et al., 2016). There are many studies conducted on Mekong River water quality in neighboring provinces of An Giang (Huong et al., 2006; Nhan & Nhan, 2014; Dieu et al., 2016; Tam et al., 2021). Some studies were conducted on surface water in An Giang (Lien et al., 2016; Nguyen et al., 2021; Phat et al., 2019). The previous studies conducted in An Giang did not focus on assessing the impact of residential areas and industrial zones/clusters on water resources, and the indicators used in these surveys were still limited. In this study, water samples were collected in June 2021 (dry season), analyzed physio-chemical parameters, and calculated Water Quality Index to obtain information on levels and characteristics of pollution. Thereby, the study provides an overview of the surface water quality of the Mekong River affected by domestic and industrial wastewater in An Giang province, which has great significance for the control of the province's water quality. This new research has most recent data and parameters than previous studies. The results are the foundation for making recommendations to the citizens and proposing environmental solutions in the upcoming time. Data of the study are a useful source of information to help the local authority take positive actions of management, environmental protection, and response to climate change in the current situation. The research is meaningful in providing data, knowledge, and references in environmental assessment.

Previous studies have reported that water quality has widely fluctuated among the provinces. A previous study showed that the maximum pH of surface water pollution in Mekong Delta, Vietnam was 8.6 (Wilbers et al., 2014). The temperature and pH of the mainstream and tributaries of the Hau River were suitable for aquatic life in most of the sampling locations (Lien et al., 2016). DO of the mainstream and tributaries of the Hau River fluctuated at 1.76–7.96 mg/L, averaging 4.9±1.4 mg/L (Lien et al., 2016). The DO of surface water affected by residential and industrial areas in Can Tho province was 4.4 mg/L and 4.8 mg/L, respectively (Tam et al., 2021). TSS of the Tien River surface water fluctuated at 9–475 mg/L (Dieu et al., 2016). TSS in the rainy season was higher than in the dry season (Lien et al., 2016). The TSS of surface water affected by residential and industrial areas in Can Tho province was 35.6 mg/L and 39.8 mg/L, respectively (Tam et al., 2021). The average COD value of the Tien River surface water was 14.3±6.3 mg/L (Lien et al., 2016). COD and BOD of the mainstream and tributaries of the Hau River fluctuated at 2–13 mg/L and 2–16 mg/L, respectively (Dieu et al., 2016). In Can Tho province, BOD_5 and COD of surface water were affected by residential areas were 11.4 mg/L and 18.8 mg/L, BOD_5 and COD of surface water were affected by industrial areas were 8.7 mg/L and 14.1 mg/L, respectively (Tam et al., 2021).

The average $N\text{-}NO_3^-$ value of surface water of the Tien River was 0.11±0.07 mg/L (Lien et al., 2016). $N\text{-}NH_4^+$ of the mainstream and tributaries of the Hau River fluctuated at 0.02–0.60 mg/L (Dieu et al., 2016). The value of NO_3^- of surface water affected by residential areas and industrial areas in Can Tho province was 0.47 mg/L and 0.61 mg/L, respectively, while the value of NH_4^+ was 1.18 mg/L and 0.53 mg/L (Tam et al., 2021). The average value of $P\text{-}PO_4^{3-}$ in the surface water of the Tien River is 0.1±0.07 mg/L (Lien et al., 2016). $P\text{-}PO_4^{3-}$ of the mainstream and tributaries of the Hau River fluctuates at 0.06–0.47 mg/L (Dieu et al., 2016). PO_4^{3-} of surface water affected by residential and industrial areas in Can Tho province were 1.17 mg/L and 2.12 mg/L, respectively (Tam et al., 2021). The previous study reported that total Coliforms in surface water pollution in Mekong Delta, Vietnam was 2,500,000 CFU/100 mL (Wilbers et al., 2014). The study by Wilbers et al. (2014) indicated that the value of arsenic and mercury in the surface water pollution in the Mekong delta was 44.1 μg/L and 45.5 μg/L, respectively. The study of Phat et al. (2019) showed that indicators of arsenic were not detected in the surface water of the Tien River flowing through the Tan Chau River in Tan Chau town, An Giang province. Dieu et al. (2016) showed that the concentration of toxic dissolved metals in surface water of the mainstream and tributaries of the Hau River was low.

Many previous studies in Vietnam used the national technical regulations on surface water quality (QCVN 08-MT:2015/BTNMT) to assess surface water quality. For example, previous studies have reported that the value of PO_4^{3-}, NH_4^+, and NO_2^- of surface water quality of the Tien River flowing through the Tan Chau River in Tan Chau town, An Giang province exceeded the allowable limits (Phat et al., 2019). In addition, the concentrations of TSS, BOD, COD, N-NH_4^+, N-NO_2^-, P-PO_4^{3-}, Coliform, and *E. coli* in surface water quality in Dong Thap province exceed the allowable limits (Giao et al., 2021). However, pH, temperature, DO, BOD and COD parameters of surface water quality in some canals connecting the Tien River and the Hau River in Vinh Long province, Dong Thap province, and Tien Giang province has within the allowable limits (Nam et al., 2009).

The research conducted by Nguyen et al. (2021) found that the surface water in An Giang was contaminated by organic matters, suspended solids, and Coliforms. On the other hand, the surface water of the Hau River was quite nutritious, especially in the areas affected by aquaculture and agricultural production (Lien et al., 2016). Surface water quality affected by the residential area was the worst compared to surface water affected by the industrial zone, fruit area, and rice field area in Can Tho province. The surface water quality in Can Tho province has decreased due to poor wastewater management by companies and industrial parks (Tam et al., 2021). Another study found that significant degradations were mainly associated with human disturbance and were particularly apparent in sites distributed along the artificial canals in the Vietnam delta, where intensive population growth and agricultural development (Chea et al., 2016). The increase in population density, the number of industrial establishments, the number of commercial and service establishments, and the number of livestock and poultry are the main reasons for the increase of organic matter content in the surrounding surface water. Meanwhile, the increase in rice area, rice production, aquaculture area, and aquaculture production are the main reasons for the increase of suspended solids, nitrogen and the decrease of pH in the surrounding surface water (Nhan & Nhan, 2014).

The water quality index (WQI) model is a popular tool for evaluating surface water quality. In Vietnam, the water quality index was calculated according to the technical guidelines for calculation and publication of the water quality index of the Vietnam Environment Administration (VN_WQI). The previous study showed that VN_WQI values of surface water in An Giang province ranged from 15 to 71, indicating surface water quality was very bad to medium, in which the water quality in larger and smaller rivers in the dry season was less polluted than that in the rainy season due to erosion and runoff water containing waste materials in the wet season (Nguyen & Huynh, 2020). On the other hand, the research conducted by Giao et al. (2021) showed that the water quality index of surface water in Dong Thap province is ranked at level IV (poor) using the VN_WQI method, which was suitable for irrigation and other equivalent purposes.

MATERIALS AND METHODS

Study Area

In 2020, the average population of An Giang province was 1,909,335 people, and the density was 540 people/km^2. There is a high concentration of population in urban areas and a low concentration in rural areas. The migration of the population from rural to urban areas has a significant impact on the environment. The environment in the urban area is becoming more and more polluted with the progress of urbanization. In the cities, untreated or inadequately treated domestic wastewater has been discharged into the environment, and domestic waste has not been collected and treated with suitable treatment solutions. In addition, there are still production facilities and factories located in residential areas. The total amount of domestic wastewater in the province is estimated at 176,000 m^3/day.night in wastewater in the urban area is approximately 72,000 m^3/day.night. The province includes 11 districts, towns, and cities but only two wastewater treatment systems. There is the Chau Doc wastewater treatment system with a capacity of 5,000 m^3/day.night and the Long Xuyen wastewater treatment system with a capacity of 30,000 m^3/day.night which is in trial operation (An Giang Department of Natural Resources and Environment, 2020).

According to the report on the environmental status of An Giang province in the period 2016–2020, An Giang province currently has two industrial Parks: Binh Long Industrial Park and Binh Hoa Industrial Park, and eight industrial clusters that are operating and new industrial zones and clusters will be constructed as planned. The centralized wastewater treatment system in Binh Hoa Industrial Park with a capacity of 2,000 m^3/day.night is in operation, and the centralized wastewater treatment system in Binh Long Industrial Park with a capacity of 4,000 m^3/day is still building. Up to now, the province has invested in infrastructure for eight industrial clusters and put them into operation. However, it has not yet been invested in building a centralized wastewater collection and treatment system. Investment projects in these industrial clusters must have separated wastewater treatment systems if the activities generate wastewater. The industry of An Giang province mainly focuses on processing industries of foodstuffs, agricultural products, aquatic products, garments, leather shoes, and construction materials (An Giang Department of Natural Resources and Environment, 2020).

Location of Water Sampling

Surface water samples were collected at five sampling points from affected urban areas and two surface water sampling points from industrial parks and clusters. The sample collection schedule was in June 2021 (dry season). Figure 1 shows the location map of surface water sampling. Table 1 shows the code, coordinates, and characteristics of the sampling location.

Table 1

Location of sampling

No.	Code	Coordinate	Location	Characteristics
Basin affected by urban area				
1	UB1	554.699 1.194.414	Long Thanh Ward, Tan Chau town	The total population of Long Thanh Ward is 13,979 people. The location is affected by wastewater from many production and business activities and residents in the area. It is the location affected by wastewater from the Tan Chau urban area on the Tien River.
2	UB2	571.273 1.166.986	Cho Moi commune, Cho Moi district	The total population of Cho Moi commune is 11,318 people. The location is affected by wastewater from many production and business activities and residents in the area. It is the location affected by wastewater from Cho Moi urban area on the Tien River.
3	UB3	581.029 1.162.307	My Luong commune, Cho Moi district	The total population of the My Luong commune is 13,540 people. The location is affected by wastewater from many production and business activities and residents in the area. It is the location affected by wastewater from the My Luong urban area on the Tien River.
4	UB4	576.273 1.147.845	My Long ward, Long Xuyen city	The total population of the My Long ward is 16,750 people. The location is affected by wastewater from many production and business activities and residents in the area. It is the location affected by wastewater from the Long Xuyen urban area on the Hau River.
5	UB5	553.659 1.168.368	Cai Dau commune, Chau Phu district	The total population of the Cai Dau commune is 16,958 people. The location is affected by wastewater from many production and business activities and residents in the area. It is the location affected by wastewater from Cai Dau urban area on the Hau River (Primary canal)

Table 1 *(Continue)*

No.	Code	Coordinate	Location	Characteristics
Basin affected by industrial parks and industrial clusters				
1	ID1	554.720 1.168.808	Binh Long Industrial Park, Binh Chanh Hamlet, Binh Long Commune, Chau Phu District	Binh Long is a mixed industrial park with many industries, mainly seafood processing, aquatic food processing, and fruit and vegetable processing. The location is affected by wastewater from Binh Long industrial area on the Hau River.
2	ID2	577.294 1.146.119	My Quy Industrial Cluster, Long Xuyen city	Seafood processing is the main industry in My Quy Industrial Cluster. The location is affected by industrial wastewater from My Quy Industrial Cluster on the Hau River.

Methods of Sampling, Preserving, Measuring, and Analyzing Water Samples

The parameters for assessment included: Temperature, pH, Dissolved Oxygen (DO), Total Suspended Solids (TSS), Chemical oxygen demand (COD), Biological oxygen demand (BOD_5), Nitrate (NO_3^- calculated by N), Phosphate (PO_4^{3-} calculated by P), Ammonium (NH_4^+ calculated by N), Coliform, Arsenic (As), Lead (Pb), Mercury (Hg), Benzene hexachloride, Dieldrin.

The order and environmental monitoring methods are implemented under Circular 24/2017/TT-BTNMT on promulgating technical regulations on environmental monitoring and Vietnamese standards and regulations (Vietnam Ministry of Natural Resources and Environment, 2017). Furthermore, methods of sampling, preservation and analysis of samples are under the Vietnam National standard on water quality, as displayed in Tables 2, 3, and 4 (Vietnam Ministry of Science and Technology, 1995; Vietnam Ministry of Science and Technology, 1996; Vietnam Ministry of Science and Technology, 2008; Vietnam Ministry of Science and Technology, 2011a; Vietnam Ministry of Science and Technology, 2011b; Vietnam Ministry of Science and Technology, 2011c; Vietnam Ministry of Science and Technology, 2016).

Table 2

Method of measuring parameters at the location

No.	Parameter	Methods of measuring	Measuring range
1	Temperature	SMEWW 2550B:2012	4-50°C
2	pH	TCVN 6492:2011	2-12
3	DO	TCVN 7325:2016	0-20 mg/L

Table 3

Methods of sampling, preservation of samples

No.	Parameter	Methods of sampling	Methods of sample preservation
1	Surface water sample	TCVN 6663-1:2011 TCVN 5994:1995 TCVN 6663-6:2008	TCVN 6663-3:2016

Table 4

Method of analyzing water samples in a laboratory

No.	Parameter	Method of analyzing	Measuring range
1	Chemical oxygen demand (COD)	SMEWW 5220C:2012	3 mg/L
2	Biological oxygen demand (BOD_5)	SMEWW 5210B:2012	1 mg/L
3	Total Suspended Solids (TSS)	SMEWW 2540D:2012	10 mg/L
4	Nitrate (NO_3^- calculated by N)	SMEWW 4500-NO3-.E:2012	0.01 mg/L
5	Phosphate (PO_4^{3-} calculated by P)	SMEWW 4500-P.E:2012	0.03 mg/L
6	Coliform	TCVN 6187-2:1996	3 MPN/100ml
7	Arsenic (As)	SMEWW 3114B:2012	0.0006 mg/L
8	Lead (Pb)	TCVN 6665:2011	0.004 mg/L
9	Mercury (Hg)	SMEWW 3112B:2012	0.0003 mg/L
10	Ammonium (NH_4^+ calculated by N)	SMEWW 4500 -NH3.B&F:2012	0.03 mg/L
11	Benzene hexachloride	US.EPA Method 3510C + US.EPA Method 3630C US.EPA Method 8081B	0.005 µg/L
12	Dieldrin	US.EPA Method 3510C + US.EPA Method 3630C US.EPA Method 8081B	0.005 µg/L

Machines and equipment used to analyze water samples include a meter to measure temperature, DO, pH - PCD 650/ pH 600 Eutech; Satellite navigation device - GPS map 76CSX Garmin; Incubator-LI20-Shellab; Digester block-Merck TR420; Microbiology cabinet cabin- AC2-4E1 Esco; Drying cabinet-ED105 Binder; UV-vis-2700 Labomed; Atomic absorption spectrophotometric-AAS 400 Perkin Elmer; Digital analytical balance-PA224S Satorius brand. These machines and equipment are calibrated once a year.

Water Quality Assessment

The analytical results of water samples are compared with surface water quality parameters according to QCVN 08-MT:2015/BTNMT-National technical regulation on surface water quality of Vietnam (Vietnam Ministry of Natural Resources and Environment, 2015).

The Water Quality Index (WQI) is calculated based on the Decision 1460/QD-TCMT on promulgating technical guidelines for calculation and Vietnam water quality index (VN_WQI) (Vietnam Environment Administration, 2019). Parameters used to calculate WQI in this study include temperature, pH, DO, BOD_5, COD, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, and Coliform.

For parameters of BOD_5, COD, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, Coliform, and WQI are calculated according to Equations 1 and 2:

$$WQI_{SI} = \frac{q_i - q_{i+1}}{BP_{i+1} - BP_i}(BP_{i+1} - C_p) + q_{i+1} \quad [1]$$

In particular:

BP_i: lower limit concentration of monitoring parameters corresponding to level i;

BP_{i+1}: upper limit concentration of monitoring parameters corresponding to level i+1;

q_i: WQI at level i given corresponds to $BP_{i;}$

q_{i+1}: WQI at level i+1 corresponds to $BP_{i+1;}$

C_p: Monitoring parameters are taken into account.

Calculating WQI_{DO}:

$$WQI_{SI} = \frac{q_{i+1} - q_i}{BP_{i+1} - BP_i}(C_p - BP_i) + q_i \quad [2]$$

In particular:

C_p: Saturated DO%;

BP_i. BP_{i+1}. q_i. q_{i+1} are the values corresponding to the level i, i+1

Calculating WQI_{pH}:

If pH < 5.5 or pH > 9, $WQI_{pH} = 10$.

If 5.5 < pH < 6, using formula [2] to calculate WQI_{pH}

If 6 ≤ pH ≤ 8.5, $WQI_{pH} = 100$.

If 8.5 < pH < 9, using formula [1] to calculate WQI_{pH}

After calculating WQI for each of the above parameters, the WQI calculation is applied according to Equation 3:

$$WQI = \frac{WQI_I}{100}\left(\frac{\prod_{i=1}^{n} WQI_{II}}{100}\right)^{\frac{1}{n}}\left(\frac{\prod_{i=1}^{m} WQI_{III}}{100}\right)^{\frac{1}{m}}\left[\frac{1}{k}\left(\sum_{i=1}^{k} WQI_{IV}\right)^2 \frac{1}{l}\left(\sum_{i=1}^{l} WQI_V\right)\right]^{\frac{1}{3}} \quad [3]$$

In particular:

WQ_I: Calculation results for pH

WQ_{II}: Calculation results for the group of pesticides parameters

WQ_{III}: Calculation results for the group of heavy metal parameters
WQ_{IV}: Calculation results for the group of organic and nutritional parameters
WQ_{V}: Calculation results for microbiological parameters

Table 5 displays the water quality rating based on the water quality index range and recommendation of surface water usage.

Table 5
Water Quality Rating and recommendation of usage according to Vietnam Environment Administration

Water quality Index Range	Water Quality Rating	Color	Intended use
91-100	Excellent		Good for water supply
76-90	Good		For water supply but needs appropriate treatment measures
51-75	Medium		For irrigation and other similar purposes
26-50	Poor		For water transport and other similar purposes
10-25	Polluted		Water is heavily polluted, needs future treatment
<10	Serious polluted		Water is poisoned, needs treatment

Note. From "Decision 1460/QD-TCMT on promulgating technical guidelines for calculation and Vietnam water quality index (VN_WQI)" by Vietnam Environment Administration, 2019

RESULTS AND DISCUSSION

Table 6 displays the analytical results of surface water affected by urban areas. Table 7 displays the analytical results of surface water affected by industrial parks and industrial clusters. The water temperature at the sampling locations ranges from 29.5 to 32.1^{0}C in the area affected by domestic wastewater and ranges from 31.7 to 32.3^{0}C in the area affected by industrial wastewater. Since the study area is completely within the An Giang province and the air temperature in the area is relatively uniform, the water temperature between the sampling locations in the study areas does not have a significant difference. However, the temperature varies between 25^{0}C to 35^{0}C, where most metabolic activities within a living organism occur with maximum ease and efficiency (Asthana, 2006). Therefore, the water temperature in sampling locations generally does not affect the area's aquatic life, consistent with Lien et al. (2016). While the average temperature in An Giang from 2016 to July 2020 is about 28^{0}C (An Giang Department of Natural Resources and Environment, 2020), the water temperature in sampling locations is slightly higher than the area's average temperature. Since the time of sampling is in the dry season, the water temperature was higher than that in the rainy season. Higher temperature will increase the rate of degradation of organic materials (BOD) and decrease the solubility of oxygen in water resulting in a lower stream DO than would exist under the same condition but at a lower oxygen temperature (CH2M Hill, 1979).

The pH of surface water affected by urban areas ranges from 7.22 to 7.63, and the pH of surface water affected by industrial parks and clusters ranges from 7.12 to 7.26. According to the National Technical Regulation on Surface Water Quality of Vietnam, column A1 (6–8.5), these values are all within the allowable limits. This result is consistent with Wilbers et al. (2014) and Lien et al. (2016).

Dissolved oxygen (DO) at the sampling locations affected by urban areas ranges from 2.81 to 6.05 mg/L. According to the national technical regulation on surface water quality of Vietnam, only the DO in the locations of Tan Chau residential area, Tan Chau town (6.05 mg/L) is still within the allowable limit (≥6 mg/L); the remaining locations are lower than the allowable value from 1.07 to 2.81 times. DO at sampling locations affected by industrial zones and clusters ranges from 4.95 to 5.98 mg/L, lower than the allowable limit from 0.83 to 0.99 times. This result is consistent with Lien et al. (2016) and Tam et al. (2021) that the value of DO was low. The average value of DO in this study is higher than that in the study of Lien et al. (2016) but lower than that in the study of Tam et al. (2021).

Total Suspended Solids (TSS) of surface water at five locations affected by domestic wastewater range from 45.00 to 59.00 mg/L are 2.25 to 2.95 times higher than the allowable limits in National technical regulation on surface water quality of Vietnam (20 mg/L). TSS at two locations affected by industrial wastewater has values ranging from 47.67 to 52.00 mg/L, which are 2.38 to 2.60 times higher than the allowable limits. This result is consistent with the previous of Tam et al. (2021). However, the average value of TSS in this study is many times lower than that in the study of Dieu et al. (2016). In addition, this study was conducted for the dry season, making the result of TSS lower than results in the rainy season or the whole year.

The Chemical Oxygen Demand (COD) at five sampling locations in urban areas values from 18.67 to 91 mg/L; these values exceed 1.87 to 9.10 times compared to the limits in National Technical Regulations (10 mg/L). The COD at sampling locations in industrial parks and clusters ranges from 20 to 27 mg/L, exceeding the permissible limits from 2.00 to 2.70 times. The COD in this study is much higher than data in the previous studies by Lien et al. (2016) and Dieu et al. (2016). However, this result is consistent with Tam et al. (2021). This comparison shows that the organic pollution of the surface water of the Mekong River has increased over time due to socio-economic development.

Biological Oxygen Demand (BOD_5) of surface water affected by urban areas ranges from 12.67 to 63.00 mg/L, exceeding the allowable limit (4 mg/L) from 3.17 to 15.75 times, according to the National Technical Regulation on surface water quality of Vietnam.

On the other hand, BOD_5 of the surface water affected by the industrial parks has values ranging from 12.67 to 16.00 mg/L, exceeding the permissible limits from 3.17 to 4.00 times. These values are higher than the results in the study of Ut et al. (2016), Dieu et al. (2016), and Tam et al. (2021).

BOD and COD are the main parameters analyzed to indicate the degree of pollution in the river. BOD is the measurement of oxygen required to decompose organic matter biologically under aerobic conditions. In contrast, COD measures the total oxygen required to oxidize all biologically available and inert organic matter into carbon dioxide and water. BOD values thus are always smaller than COD values. Thus, BOD and COD are two widely used parameters for organic pollution measurements. BOD:COD ratio is a reliable and useful indicator of the river's organic matter content under tropical climate conditions (Aik & Hamid, 2015). Wastewater with high COD to BOD ratio indicates that a substantial part of organic matter will be difficult to degrade biologically (Von, 2015). Therefore, depending on the value of the COD/BOD_5 ratio, conclusions can be drawn about the biodegradability of the wastewater and the treatment process to be employed (Mogens et al., 2008). In this study, the COD/BOD_5 ratio obtained for the sampling locations affected by urban areas varies between 1.44 to 1.74. The sampling locations affected by industrial parks and clusters vary from 1.58 to 1.69. These ratios are considered low. That means the biodegradable fraction in the surface water is high, which is a good indication for biological treatment (Mogens et al., 2008; Von, 2015).

Nitrate (NO_3^-) at sampling locations ranges from 0.02 to 0.19 mg/L for areas affected by urban areas and 0.06 to 0.19 mg/L for industrial parks and clusters affected. According to the National Technical Regulation on surface water quality of Vietnam, these values are within the allowable limits (2 mg/L). These values are lower than the Tam et al. (2021) study results but consistent with the study of Dieu et al. (2016).

Ammonium (NH_4^+) at sampling locations affected by urban wastewater ranges from 0.90 to 2.78 mg/L. According to the National Technical Regulation on surface water quality of Vietnam, ammonium value at all locations exceeds permissible value (0.3 mg/L) from 3.00 to 9.27 times. Ammonium (NH_4^+ calculated by N) at sampling points affected by industrial parks and clusters ranges from 0.46 to 1.81 mg/L exceeding the allowable limits from 1.53 to 6.03 times. These values are higher than the Dieu et al. (2016) study results but consistent with the study of Tam et al. (2021).

Phosphate (PO_4^{3-}) at the sampling locations affected by urban areas ranges from 0.06 to 0.25 mg/L. Although the values of Phosphate at the sampling point of Tan Chau residential area, Tan Chau town, and Cai Dau residential area, Chau Phu district exceeds the permissible value (0.1 mg/L) according to the National Technical Regulation on surface water quality of Vietnam, the remaining sampling locations are still within the allowable limits. In the sampling points affected by industrial parks and industrial clusters, the

Phosphate ranges from 0.03 to 0.09 mg/L and is within the allowable limits. These values are lower than the results in the study of Dieu et al. (2016) and Tam et al. (2021) but are consistent with the result in the study of Lien et al. (2016).

Parameters of Coliform at sampling locations affected by domestic wastewater value from 2,967 to 215,333 MPN/100 mL that exceed the permissible limit from 1.19 to 86.13 times compared to the National Technical Regulations on surface water quality in Vietnam (2,500 MPN/100 mL). Parameters of Coliform at sampling points in industrial parks and clusters range from 4,800-3,667 MPN/100 mL, all values exceeding the allowable limits from 1.92 to 5.47 times. This result is higher than the value of Coliform in the study to assess the water quality of the Tien River and the Hau River in some residential areas conducted by Huong et al. (2006). The results show that Coliform in surface water affected by domestic wastewater is much higher than in surface water affected by industrial wastewater. Coliform organisms are frequently used as indicators of human pollution. In addition, total Coliform is often used as an indicator of waste effluent disinfection.

Analytical results of all surface water samples show that As, Pb, Hg, Benzene hexachloride, and Dieldrin are not detected in water samples. These results are similar to Phat et al. (2016), which do not detect As in the Tien River. However, these results are different from Dieu et al. (2016), in which concentrations of toxic dissolved metals including As, Pb, and Hg in surface water of the mainstream and tributaries of the Hau River were low.

Therefore, most of the water samples exceed the allowable limits of TSS, DO, BOD_5, COD, NH_4^+, and Coliform according to the National Technical Regulation on the surface water quality of Vietnam. Temperature, pH, NO_3^-, PO_4^{3-} are mostly at suitable levels and within allowable limits. As, Pb, Hg, Benzene hexachloride, and Dieldrin are not detected at all sampling points. This result shows that the surface water of the Mekong River in An Giang is contaminated by organic matters, suspended solids, and coliforms, which is consistent with the findings of Nguyen et al. (2021) and Lien et al. (2016).

For surface water sources affected by domestic wastewater, the main cause of water pollution is that most of the domestic wastewater discharged into the river is untreated. Many wastewater and solid waste from trading, production, and business activities in markets, residential areas, and densely populated urban centers along the Tien River and the Hau River are discharged into water sources. The surface water affected by the Cai Dau urban area is the most polluted location with the highest values of parameters. This location is the primary canal connected to the mainstream with a narrow surface, no strong flow, low dispersion capacity, and low self-cleaning. Therefore, a high concentration of pollutants dispersed into the environment causes local pollution. For surface water sources affected by industrial wastewater, the main reason for pollution is that the wastewater has not been thoroughly treated and has not met the standards for discharge into water sources. The development of residential areas and industrial parks and clusters has caused a deterioration of the surface water quality of the Mekong River in An Giang province. The finding is consistent with the results of Nhan and Nhan (2014), Chea et al. (2016), and Tam et al. (2021).

Table 6
Analytical results of surface water affected by urban area

Parameters	Location									
	UB1		UB2		UB3		UB4		UB5	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Temperature (^{0}C)	30.7		29.5		30.3		32.1		30.2	
pH	7.63		7.40		7.41		7.46		7.22	
DO (mg/L)	6.05	0.07	4.98	0.10	5.15	0.09	5.59	0.14	2.81	0.12
TSS (mg/L)	54.33	2.08	51.00	2.65	45.00	2.00	48.67	2.08	59.00	4.36
COD (mg/L)	29.67	4.04	23.67	2.52	25.00	1.00	18.67	2.08	91.00	3.00
BOD_5 (mg/L)	19.00	2.65	13.67	2.08	14.33	1.16	12.67	1.53	63.00	2.65
Nitrate (mg/L)	0.10	0.01	0.13	0.00	0.19	0.01	0.07	0.00	0.02	0.01
Phosphate (mg/L)	0.17	0.02	0.06	0.01	0.06	0.01	0.07	0.01	0.25	0.02
Ammonium (mg/L)	1.09	0.06	0.90	0.05	0.90	0.05	0.95	0.04	2.78	0.10
Coliform MPN/100 mL	17,000	3,464	30,000	13,892	11,633	8,445	2,967	1,155	215,333	211,888
As (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pb (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hg (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzene hexachloride (µg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dieldrin (µg/L))	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Note. ND = Not detected

Table 7
Analytical results of surface water affected by industrial parks and industrial clusters

Parameters	Location				Column A1-Regulation
	ID1		ID2		
	Mean	SD	Mean	SD	
Temperature (^{0}C)	31.7		32.3		
pH	7.12		7.26		6-8.5
DO (mg/L)	5.98	0.06	4.95	0.03	≥6
TSS (mg/L)	47.67	1.53	52.00	2.65	20
COD (mg/L)	27.00	1.00	20.00	1.73	10
BOD_5 (mg/L)	16.00	1.73	12.67	0.58	4
Nitrate (mg/L)	0.19	0.00	0.06	0.00	2
Phosphate (mg/L)	0.09	0.01	0.03	0.00	0.1
Ammonium (mg/L)	1.81	0.09	0.46	0.04	0.3
Coliform (MPN/100 mL)	13,667	6,429	4,800	2,606	2,500
As (mg/L)	ND	ND	ND	ND	0.01
Pb (mg/L)	ND	ND	ND	ND	0.02
Hg (mg/L)	ND	ND	ND	ND	0.001
Benzene hexachloride (μg/L)	ND	ND	ND	ND	0.02
Dieldrin (μg/L)	ND	ND	ND	ND	0.1

Note. ND = Not detected

The level of water pollution due to the impact of urban areas, industrial parks, and industrial clusters calculated by the WQI index is shown in Figure 2.

WQI of location affected by urban areas and industrial parks, industrial clusters range from poor level (able to be used for water transport and other similar purposes) to good level - (able to use for water supply but needs appropriate treatment measures).

Long Xuyen city's urban area affects the two sampling points with the highest WQI, reaching a good water level (WQI = 79). The location affected by the My Quy industrial cluster in Long Xuyen city (WQI = 76) on the Hau River, water on this level can be used for domestic water supply purposes but needs appropriate treatment measures. Next, the locations affected by Tan Chau urban area, Tan Chau town (WQI = 35), Cho Moi urban area, Cho Moi district (WQI = 36), My Luong urban area, Cho Moi district (WQI = 36), on the Tien River and Binh Long industrial park, Chau Phu district on the Hau River (WQI = 36) are rated poor water level, water on this level can be used for water transport and other similar purposes. WQI is the lowest in the surface water area affected by Cai Dau urban area, Chau Phu district on the Hau River (WQI = 26), which is poor. The causes of the poor water quality and low WQI ($26 \leq WQI \leq 50$) are the high value of Coliform in the water and the high value of other parameters participating in the calculation of WQI such as DO, COD, $BOD_{5,}$ and Ammonium that exceeds the allowable limits. The values of WQI in the sampling locations are higher than the values in the study of Nguyen and Huynh (2020). Most sampling locations have the value of WQI ranked at a poor level, consistent with the study findings of Giao et al. (2021).

Based on the results of this study, it is recommended that people should not directly use water of the Tien River and Hau River in An Giang for drinking and domestic purposes to ensure their health in the long term. Appropriate water treatment measures are necessary if people want to use this water source for drinking and domestic purposes. In the coming time, authorities need to monitor and take measures to treat wastewater in markets, commercial centers, and urban areas to ensure the wastewater quality before discharging into the river based on regulations on discharge. In addition, authorities need to monitor the surface water quality affected by waste sources in industrial zones and clusters to take the most appropriate and strict management measures and promptly warn people about using water for domestic purposes.

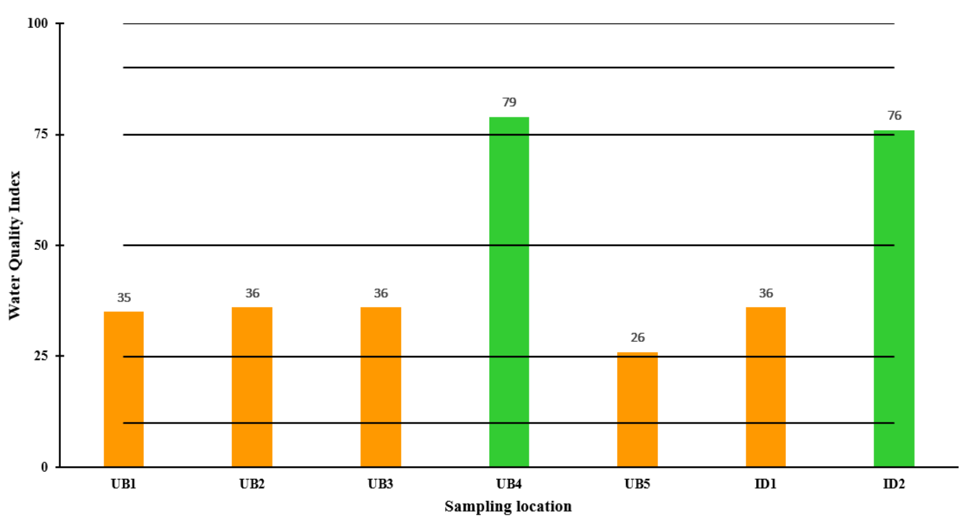

Figure 2. Water Quality Index of sampling location

CONCLUSION

Domestic and industrial wastewater have polluted the surface water of the Tien River and the Hau River, two important rivers of the lower Mekong flowing through An Giang province. The pollution shows in parameters of TSS, DO, BOD_5, COD, $N\text{-}NH_4^+$, and Coliform that exceeds allowable limits. Other parameters of temperature, pH, N-NO_3^-, PO_4^{3-} are mostly at suitable levels and within the allowable limits compared with the National Technical Regulation on surface water quality of Vietnam. As, Pb, Hg, Benzene hexachloride, and Dieldrin are not detected at all sampling points. In general, most sampling locations have the water quality index at a poor level, can be used for water transport, requires appropriate treatment before being used for domestic purposes, and have appropriate water quality management measures in place. Sampling location in the urban area of Long Xuyen city has the highest water quality (highest WQI) at a good level. Cai Dau urban area, Chau Phu district, has the lowest water quality (lowest WQI) at the poor level. In the coming time, authorities need to monitor and take appropriate measures to treat and manage wastewater from urban areas and industrial parks/clusters.

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